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Performance improvement and exhaust emissions reduction in biodiesel operated diesel engine through the use of operating parameters and catalytic converter: A review

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ABSTRACT

Diesel engines have high efficiency, reliability and durability together with their low operating cost. These important features make them to be widely used in the transportation, automotive, agricultural application and industrial sector. These wide fields of usage lead to the increasing requirements of petroleum derived fuel and going for depletion of petroleum fuel shortly. Hence, it is essential to go for an alternate fuel to diesel and effective control of the various pollutants emitted by the diesel engines. The major pollutants emitted by the diesel engines are unburned hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter (PM), sulphur oxides (SO_x) and lead. These pollutants can cause health problems to human beings and will have an impact on the environment such as climate change, global warming, acid rain, ozone depletion and photo chemical smog. Therefore, the researchers are intended to find out the viable substitute alternate fuel for diesel and control of pollutants from compression ignition (CI) engines. The biodiesel can be used as alternate for diesel, which is a non-fossil fuel, easily available and cheaper. The main drawbacks of biodiesel operated CI engine are reduced performance and increased NO_x emission. In order to improve the performance and to reduce exhaust emissions, suitable methods have to be incorporated. Hence, in the present review a detailed study has been carried out with the operating parameters and catalytic converter in biodiesel operated engine, so that its performance can be improved and exhaust emissions were reduced.

1. Need for alternate fuel

The transport sector is an important component of the economy which has an impact on the development and the welfare of the population. Internal Combustion (IC) engines are mainly used for transportation in this era. Fuel depletion and environmental pollution due to IC engines force the researchers to find various alternate fuels and effective pollution control methods.

Biodiesel has received much attention in the past decade due to its ability to replace fossil fuels, which are likely to run out within a country. Especially, the environmental issues concerned with the exhaust gas emissions by the usage of fossil fuels and also encourage the usage of biodiesel, which has to be ecofriendly for more than fossil fuels.

1.1. Effect of biodiesel-diesel blend on performance and emission

Buyukkaya [11] has reported that brake specific fuel consumption (BSFC) of the rapeseed oil and its blends such as B5, B20, B70 and B100 fuels were observed to be higher by 2.5%, 3%, 5.5% and 7.5% respectively than that of the diesel fuel, respectively. The biodiesel diesel blend has lower smoke opacity values as compared to that of diesel fuel and the reduction was 45% with B70 while it was 60% with pure biodiesel. Qi et al. [28] have observed that the BTE of soya bean biodiesel and its blends lower than that of diesel. The lowest BSFCs are 240.53, 257.16, 259.91, 263.88, and 270.35 g/kW h for diesel fuel, B30, B50, B80 and B100 respectively. The CO and smoke emissions were reduced considerably for soya bean biodiesel and its blends were compared with diesel fuel. The NO_x was slightly higher for soyabean biodiesel and its blends when compared to that of diesel fuel. Karabektas et al. [22] have found that the BSFC of diesel and B15 is 0.265 and 0.270 g/kW h respectively and the BTE for B15 is much closer to that of diesel to diesel. The ethanol and methanol blends yielded lower brake power (BP), higher SFC and lower CO emission. Jinlin Xue et al. (2010) have mentioned that NO_x emission increases when using bio diesel and this was due to the higher oxygen content, cetane number and different injection characteristics. Further, the biodiesel has lower CO, HC and smoke emissions than that of

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diesel. Tesfa et al. [46] have seen that the various biodiesels such as waste oil, rapeseed oil and corn oil were used in diesel engine and didn't result in any significant differences in peak cylinder pressure and heat release rate. The use of biodiesel increases the BSFC of the engine by 2.5%, 5%, 10% and 15% for B10, B20, B50 and B100 blends increased by respectively compared to that of diesel and it is due to its lower heating value, higher viscosity and density. Tesa (2014) has found that the NO_x emission was higher for corn oil biodiesel and its blends. The B100 biodiesel gives in 15%, 40%, and 30% reduction for CO, CO_2 and HC emissions respectively when compared to that of diesel. Rakopoulos et al. [29] have concluded that various biodiesels gives lower PM emission due absence of sulphur but has higher soot emission due to heavier molecules of biodiesel. The NOx emission of biodiesel is lower due to the higher cetane index of biodiesel which is not matching with the report of most authors. Further, the CO and HC emissions of biodiesels are lower than that of diesel. Altin et al. [31] have also stated that PM for vegetable oils were higher than that of diesel fueled, but on the other hand NO_2 emission was less.

Lin et al. [6] have observed that the various biodiesels such as soybean oil, peanut oil, corn oil, sunflower oil, rapeseed oil, palm oil, palm kernel oil, and waste fried oil have lower carbon, hydrogen, and sulphur content and higher oxygen content, when compared to that of diesel which results in higher BSFC. The smoke emission of biodiesel is 72.73% lower than diesel. However, maximum NOx emission of diesel is 466 ppm and biodiesel is 587 ppm at peak load and is due to enhanced combustion that resulted in higher temperature and pressure during combustion. The diesel engine fueled with vegetable oil methyl ester could potentially shows a reduction in the exhaust gas temperature (EGT), smoke and total hydrocarbon (THC) emission. Nandi et al. [39] have been seen that increase in the BTE and decrease in the SFC were observed in the case of esterified mahua oil (at 75% mahua oil blends) compared to that of diesel fuel. Puhan et al. [41] have SFC of mahua biodiesel (MOME) is 20% higher than that of diesel and the BTE was 13% lower than that of diesel. The CO, HC, Smoke and NOx emissions for MOME were reduced by 30%, 35%, 11% and 4% respectively. Puhan et al. [41] have also reported that BTE of mahua biodiesel is 26.36% and for diesel is 26.42% at full load. The emissions of CO, HC, NOx and smoke emissions were reduced when compared to diesel but most author mentioned that there would be increase in NOx while using biodiesel. Saravanan et al. [33] have found that there was a 20% increase in the SFC and 13% loss in engine power for mahua biodiesel than that of diesel. The BTE for mahua biodiesel was at par with diesel and emissions such as CO and HC were lesser for mahua methyl ester by 26% and 20% respectively, but NOx was increased than diesel. Nurun Nabi et al. [23,24] found that the neat karanja oil has reduced CO and smoke emissions by 50% and 43% respectively, while 15% increase in the NO_x emission. The BTE for neat karanja oil and its blends was almost closer to the BTE of diesel fuel. Suresh Kumar et al. [43] have stated that the EGT was decreasing while increasing the concentration of pongamia biodiesel blends and the maximum and minimum NOx emission for B40 were 230 and 48 ppm and it was lower compared to that of B20 and B60. Sharma et al. (2012) have found that the specific gravity, calorific value and engine performance for both jatropha and cottonseed derived biodiesel were closer to that of neat diesel fuel and can be used as fuel without any modification on diesel engine. Nurun Nabi et al. [24,25] have found that exhaust emissions including PM, smoke and CO were reduced by 24%,14% and 24% respectively and 10% increase in NO_x emission for cottonseed oil and its blends was observed.

Huzayyin et al. [15] have conducted that there is a slight increase in BTE, BSFC and reduction in NO_x and soot emission for using various blends of jajoba oil. Gogoi et al. [13] have reported that the BTE of the engine was lower and there was higher BSFC for koroch seed oil. The heat release rate (HRR) occurred earlier for the koroch seed oil and it confirms the shorter ignition delay period with respect to other blends. At full load operation, the peak pressure values for diesel, B10, B20, B30 and B40 were 57.43, 57.35, 57.62, 57.31 and 57.16 bars respectively. Randazzo et al. [20] have seen that increasing biodiesel concentration in the fuel blends increases the CO and NO_x emissions and also seen that CO, HC and PM emissions were considerably reduced for biodiesel with slight modification in the fuel injection system. Liaquat et al. [19] have found that HC and CO emissions were reduced considerably and CO_2 and NO_x emissions were increased with coconut biodiesel blend ratio than that of diesel. Machanon et al. (2001) have concluded that increase in coconut biodiesel blend ratio decreases the BMEP and increases the BSFC. The coconut blend showed lower smoke and NO_x emission than that of diesel fuel. Labeckas et al. [14] have reported that the smoke and HC emissions were reduced by 30% and 25.6% respectively for shale oil but NO_x emissions increased drastically. Altun et al. [36] have found that the exhaust emissions for sesame oil was lower than that of diesel fuel, except NO_x emission. Paul et al. [12] have that the BTE for pure diesel was 29.6% and for pure jatropha was 21.2% at full load. The smoke, HC and CO emissions were decreased and NO_x, and CO_2 emissions were increased for jatropha fuel when compared to that of neat diesel fuel. Ergenc et al. [3] have reported that the BSFC at the maximum power was 285 g/kW h with diesel, and 270 g/kW h, 265 g/kW h, and 268 g/kW h with soyabean blends such as B50, B20, and B10 fuels, respectively. The CO, HC and NO_x emissions were lower than that of diesel fuel. Anbumani et al. [4] have stated that the found that lower levels of smoke, HC and NO_x emissions were observed for mustard oil and neem oil biodiesel blend. Abedin et al. [1] have found that the palm oil blends showed 5.3% higher BP than jatropha blends and 14.4% lower BSFC compared to that of jatropha blends. The palm oil blends achieved reduction of HC, CO and smoke emissions and considerable amount of reduction in NO_x emission.

Prabhakar [26] have reported that the diesel engine runs successfully at 20% blends without affecting the engine performance. Among the various vegetable edible oils, nerium biodiesel showed better performance than that of others. The nerium biodiesel showed lower smoke and HC and higher NO_x emission. Prabhakar et al. [27] have found that HC, CO and smoke emissions were reduced drastically for madhuca indica. However, CO_2 and NO_x emissions slightly increased compared to Pongamia pinnata and neat diesel fuel. Senthil et al. [37] have found that the BTE was higher for pongamia-ethanol blend when compared to jatropha-ethanol. Further, the HC, CO and smoke emissions were lower than that of jatropha-ethanol blend and diesel but at the expense of increase in NOx emission. Senthil et al. (2015) have found that CO and HC, smoke emissions were reduced for annona methyl ester (AME) considerably and NO_x emissions slightly increased for the various proportions of AME.

1.2. Summary

The literature study certainly proves beyond doubt that biodiesel could be used as the alternative for diesel engine. It has been further reported that while using the properties of biodiesel are almost equal to the diesel but at the same while operating in a diesel engine, it decreases the performance and increases NOx emission. Table 1 shows the comparative changes of engine performance such as BTE, BSFC, and engine emissions such as HC, CO, NOx, and smoke emissions in biodiesel operated diesel engine with respect to diesel.

2. Techniques to improve diesel engine performance and reduction in exhaust emissions

Several researchers conducted studies to improve the engine performance and reduction in emissions except NOx emission. Modern diesel technologies have undergone a number of design parameters, operating parameters and fuel modifications in order to meet the increasingly stringent environment regulations and to reduce the various pollutants from CI engine. The design and operating

Table 1
Comparative changes of engine performance and emissions for biodiesel blends with respect to diesel.

Feed stock of biodiesel	Performance		Emission				References
	BSFC	BTE	CO	HC	Smoke	NOx	
Rapeseed oil and its blends (B5, B20, B70 and B100)	Increase (2.5%, 3%, 5.5% and 7.5%)	Decrease	Decrease	Decrease	Decrease (B70-45%)	Increase	Buyukkaya [11]
Soya bean oil and its blends (B30, B50, B80 and B100)	Increase (240.53, 257.16, 259.91, 263.88, and 270.35 g/kW h)	Decrease	Decrease (0.05%)	Decrease	Decrease	Increase	Qi et al. [28]
Blends of ethanol, methanol and vegetable oils (B15)	Increase (0.265 g/kW h)	Decrease	Decrease	Decrease	Decrease	Increase	Karabektas et al. [22]
Vegetable oils	Increase	Decrease	Decrease	Decrease	Decrease	Increase	
Waste oil, rapeseed oil and corn oil	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Tesfa et al. [46]
Corn oil (B100)	Increase	Decrease	Decrease (15%)	Decrease (30%)	Decrease	Increase	
Various vegetable oils	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Rakopoulos et al. [29]
Various vegetable oils	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Altin et al. [31]
Various vegetable oils	Increase	Decrease	Decrease	Decrease	Decrease (72.73%)	Increase (20.6%)	Lin et al. [6]
Mahua oil	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Nandi et al. [39]
Mahua oil	Increase (20%)	Decrease (13%)	Decrease (30%)	Decrease (35%)	Decrease (11%)	Increase (4%)	Sukumar [41]
Mahua oil	Increase	Decrease (26.42%)	Decrease	Decrease	Decrease	Increase	Sukumar [42]
Mahua oil	Increase (20%)	Decrease	Decrease (26%)	Decrease (20%)	Decrease	Increase (4%)	Saravanan et al. [34]
Karanja oil	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Nurun Nabi et al. [24,30]
Pongamiapinnata methyl ester	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Kumar et al. [43]
Mixed jatropha and cotton seed biodiesel	Increase	Decrease	Decrease	Decrease	Decrease	Increase	
Cottonseed oil	Increase	Decrease	Decrease (24%)	Decrease (20%)	Decrease (14%)	Increase (10%)	Nurun Nabi et al. [24,25]
Jajoba methyl ester	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Huzayyin et al. [15]
Koroch seed oil	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Gogoi et al. [13]
Soya bean biodiesel	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Randazzo et al. [20]
Coconut biodiesel	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Liaquat et al. [19]
Coconut biodiesel	Increase	Decrease	Decrease	Decrease	Decrease	Increase	
Shale oil	Increase	Decrease	Decrease (25.6%)	Decrease (30%)	Decrease	Increase	Labeckas et al. [14]
Sesame oil	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Altun et al. [36]
Jatropha biodiesel	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Paul et al. [12]
Soya bean biodiesel	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Ergenc et al. [3]
Mustard oil and neem oil	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Anbumani et al. [4]
Palm and jatropha bio diesel	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Abedin et al. [1]
Nerium, jatropha, pongamia, mahua and neem oil	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Prabhakar [26]
Mahua oil	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Prabhakar et al. [27]
Jatropha-ethanol and pongamia-ethanol	Increase	Decrease	Decrease	Decrease	Decrease	Increase	Senthil et al. [37]
Annona oil	Increase	Decrease	Decrease	Decrease	Decrease	Increase	

parameters include improved fuel injection techniques, high compression ratio (CR), air management methods, combustion chamber design, improved oil control, adiabatic engine, etc. The fuel modification is another technique of in-cylinder treatment method such as using additives, biofuel and biodiesel blends. Many of these design changes, operating parameters and fuel modifications have also been incorporated into the CI engine to improve the performance and reduction in emissions except NOx emission. Among these methods operating parameters are used not only for controlling the emission but also improving the performance of the CI engine.

2.1. Effect of operating parameters

Balakrishnan [7] have observed that the BTE is increased up to 28.1% and BSEC is decreased up to 12.81%MJ/kW h for biodiesel with producer gas at a CR of 20. The emission reduction ensures the suitability of mixed fuel at higher CR without any modifications in the engine. Harikude et al. (2014) have found that the variation of CR showed improvement in the BTE and BSFC for waste fried methyl ester. Further, the CO and PM emissions decreases while NO_x emission increases with increase in CR for waste fried methyl ester than that of original CR. Jindal et al. [17] have found that the combined effect of CR and injection pressure (IP) increases the BTE and reduces the BSFC and also lowers the emission for jatropha biodiesel. The optimum CR was18 and injection pressure (IP) was 250 bar for the jatropha biodiesel. Sayin et al. [9] have found that the BSFC and NO_x emission increases while the BTE, smoke, CO and HC decreases with increase of the percentage of EKO biodiesel blend. Further, the BSFC and BTE increases with increase of CR, IP and injection timing (IT). It has been found that the increase of CR, IP and IT leads to decrease in various exhaust emissions. Adnan Parlak et al. [2] have found that the optimum IT was four-degree crank angle which retarded to bTDC in a LHR diesel engine compared to standard diesel engine. The NO_x emission was decreased to 40% when compared to that of diesel engine. Ashrafur et al. [5] have reviewed the influence of IT on engine performance and exhaust emission with diesel, biodiesel, alcohol and other alternate fuels. The advancement on IT showed reduction of CO, HC and increase of NO. Further, the advance in IT increases the BTE & EGT and decreases BSFC. Metin Gumus et al. [21] have found that the maximum BTE was obtained 41.31% with B100 at 24 MPa IP. The BSFC, CO_2, NO_x and O_2 emissions were increased with biodiesel blend. The smoke, HC and CO decreases due to fuel properties and combus-

tion characteristics of a biodiesel. However, the increase of IP leads to decrease of BSFC and reduction of CO_2 and NO_x emission at higher ratio of biodiesel blend. Sukumar Puhan et al. [40] have found that the optimum IP was 240 bar and at this pressure the BTE was improved and reduced HC, CO and smoke emissions but NO_x emission was increased. Sayin et al. [8] have reported that when the IT was advanced, smoke and CO emissions were decreased due to improving the reaction between fuel and oxygen. Further, the smoke, HC and CO emissions were decreased considerably and NO_x emission was increased with increase in IP for all fuel blends. Venkanna et al. [48] have found that the performance and emission characteristics of 30% pongamia biodiesel blend were better than that of diesel fuel at increased IP.

Zhu et al. [32] have reported that using diesel- Di-methoxy methane (DMM) blends improved BTE and reduced smoke and CO emissions with slight increase of NO_x emission. The advancing fuel IT improves the BTE and reduces the smoke emission with the increase of NO_x emission. Sarvi et al. [35] have observed that the lowering the burning flame temperature reduces the NO_x due to incomplete combustion and increase of CO and HC emissions. The retarding start of ignition reduces NO_x, but increases the smoke and HC emissions. Saravanan et al. [34] have reported that fuel IP contributes more in reducing the NO_x emission with minimum increase in smoke emission. Further, the retarding IT without EGR with standard IP will be the optimum combination for reduction of NOx.

2.2. Summary

Most of the research studies have indicated that the need for research in the area of engine modification so as to suit the higher blends without any drastic change in performance and emission characteristics. It was found from the literature review that the CR plays a vital role in determine the overall efficiency of the engine. The modification of the engine operating parameter such as (CR) is mandatory to optimize the overall efficiency of the engine due to difference in chemical composition and combustion characteristics between diesel and biodiesel blends. Table 2 shows the comparative changes of effect of operating parameters engine performance such as BTE, BSFC, and engine emissions such as HC, CO, NOx, and smoke emissions in biodiesel operated diesel engine with respect to standard operating parameters.

3. Techniques to reduce diesel engine NOx emission

Numerous studies have shown that the use of biodiesel in diesel engine results in slight increase in NOx emission than diesel. The NOx is a major cause of smog, ground level ozone and also a cause of acid rain. As the use of biodiesel has increased tremendously, the raise in NOx emission could become a significant barrier to expansion. The development of improved NOx emission reduction techniques is therefore of critical importance to the global environment. One of the best method for controlling emission from CI engine is the use of catalytic converter.

3.1. Effect of catalytic converters

Vallinayagam et al. [47] seen that the BTE of pine oil B50 blend with selective catalytic converter (SCR) and catalytic converter (CC) was 7.5% higher than that of diesel fuel, whereas emissions such as smoke, CO, HC and NO_x were lower by 70.1%, 67.5%, 58.6%, and 15.2% respectively than that of diesel at full load condition. The average emission of B50 with SCR and CC assembly were considerably reduced. Shane et al. (2014) have reported that, for petrol engine, the NO_x emission was reduced by 10–20% with three-way catalytic converter, but it has no effect on the BTE and BSFC. However, there was an increase in HC and CO emissions. Kumar et al. [44] have concluded that the NO_x emission for JB100 fuel increased when it was operated without three-way catalytic converter and with catalytic converter 24.4% reduction of NO_x was achieved when compared to that of diesel fuel. Khanfekr et al. [18] have reported that catalyst was applied on a car and the results were compared with noble metals such as palladium, platinum and rhodium. The CO, NO_x and HC emission were lower than that of noble catalyst metals. Durairajan et al. [10] have discussed and manufactured the nano catalytic converter by replacing expensive metals with cerium oxide and to reduce the exhaust emissions from the automobiles. The NO_x, HC and CO emissions were decreased by 84.3%, 78% and 69% respectively at full load condition. Huang et al. [45] have reported that NO_x was converted effectively into N_2 and oxygen at ambient temperature. Further, increasing O_2 concentration enhances the NO_x activity and zero NO_x emission can be achieved. Therefore, the electro-catalytic honey comb catalytic converter would achieve higher fuel efficiency and more reduction of greenhouse gases.

Subramaniam et al. [38] have concluded that diesel engine operated up to B40 blends assisted by catalytic converter with 15% EGR had showed better reduction in NO_x and improvement in the BTE. The combining of EGR with Ni coated catalytic converter showed better reduction of HC, CO and NO_x emissions. Ibrahim Aslan Resitoglu et al. [16] have reported that DOC has been used not only to reduce CO and HC emissions but also to exert a considerable influence on the performance of downstream DPF and SCR. Further, the DOC reduces PM considerably and SCR systems were highly effective to reduce the

Table 2
comparative changes of effect of operating parameters on engine performance and emissions biodiesel blends with respect to standard operating parameters.

Feed stock of biodiesel	Type of operating parameter	Performance		Emission				References
		BSFC	BTE	CO	HC	Smoke	NOx	
Biodiesel with producer gas	Increased CR	Increase (12.81%)	Increase (28.1%)	Decrease	Decrease	Decrease	Increase	Balakrishnan [7]
Waste fried methyl ester	Increased CR	Increase	Increase	Decrease	Decrease	Decrease	Increase	
Jatropha methyl ester	Increased CR and IP	Increase	Increase	Decrease	Decrease	Decrease	Increase	Jindal et al. [17]
EKO biodiesel	Increased in CR	Increase	Increase	Decrease	Decrease	Decrease	Increase	Sayin et al. [9]
Diesel	Retarded IT	Increase	Increase	Decrease	Decrease	Decrease	Decrease	Parlak et al. [2]
Vegetable oil	Advanced IT	Increase	Increase	Decrease	Decrease	Decrease	Increase	Ashrafur et al. [5]
Vegetable oil	Increased IP	Increase	Increase	Decrease	Decrease	Decrease	Increase	Gumus et al. [21]
Linolenic linseed oil	Increased IP	Increase	Increase	Decrease	Decrease	Decrease	Increase	Puhan et al. [40]
Methanol blended diesel	Advanced IT	Increase	Increase	Decrease	Decrease	Decrease	Increase	Sayin et al. [8]
Pongamiapinnata oil	Increased IP	Increase	Increase	Decrease	Decrease	Decrease	Increase	Venkanna et al. [49]
Di-methoxy methane	Advanced IT	Increase	Increase	Decrease	Decrease	Decrease	Increase	Ruijun Zhu et al. [32]
Diesel	Increased CR, start of injection and fuel injection nozzle	No effect	No effect	Increase	Increase	Increase	Decrease	Sarvi et al. [35]
Diesel	Increased IP with EGR	Increase	Increase	Decrease	Decrease	Decrease	Increase	Saravanan et al. [34]

Table 3
Comparative changes of effect of catalytic converter on engine performance and emissions biodiesel blends with respect to diesel.

Feed stock of biodiesel	In-cylinder treatment methods	Performance		Emission				References
		BSFC	BTE	CO	HC	Smoke	NOx	
Pine oil	Selective catalytic converter and catalytic converter	Decrease	Increase (7.5%)	Decrease (67.5%)	Decrease (58.6%)	Decrease (70.1%)	Decrease (15.2%)	
Diesel	Catalytic converter	No effect	No effect	Decrease	Decrease	Decrease	Decrease	
Jatropha biodiesel	Catalytic converter	Decrease	Increase	Decrease	Decrease	Decrease	Decrease (24.4%)	Kumar et al. [44]
Duel fuel	Catalysts (lanthanum, cerium, iron, manganese, cobalt, palladium and oxygen) on catalytic converter	Decrease	Increase	Decrease	Decrease	Decrease	Decrease	Khanfekr et al. [18]
Diesel	Cerium oxide catalytic converter	Decrease	Increase (69%)	Decrease (78%)	Decrease (35%)	Decrease	Decrease (84.3%)	Durairajan et al. [10]
Diesel	Catalytic converter	Decrease	Increase	Decrease	Decrease	Decrease	Decrease	Huang et al. [45]
Waste frying oil	Exhaust gas regulation (EGR) and Ni coated catalytic converter	Decrease	Increase	Decrease	Decrease	Decrease	Decrease	Subramaniam et al. [38]
Diesel	DPF and SCR	Decrease	Increase	Decrease	Decrease	Decrease	Decrease	Resitoglu et al. [16]
Diesel	catalytic converter	Decrease	Increase	Decrease	Decrease	Decrease	Decrease	

NO_x emission. Kasper et al. (2003) have reported that wash coat catalysts such as alumina, CeO_2, ZrO_2, noble metals, barium/lantana oxides can be used in three-way catalytic converter. Hence, the three-way catalyst coated converter plays a key role in reducing various pollutants such as CO, HC and NO_x in diesel engines.

3.2. Summary

There have been several attempts to reduce the NOx emission from biodiesel fueled diesel engine. In-cylinder treatment methods can be supplemented by a number of exhaust gas after treatment technologies, which are available as retrofit devices for diesel engines operated in closed spaces or in other environmentally sensitive applications. The use of exhaust gas after treatment method on diesel engine is still limited, but will significantly increase over the next decade to satisfy the coming environment regulations. The review of literature reported that the possible solutions for biodiesel NOx effect and also suggested that the use of catalytic converter as NOx control strategy is way for this review study. Table 3 shows the comparative changes of effect of catalytic converter on engine performance behavior such as BTE, BSFC, and engine emissions such as HC, CO, NOx, and smoke emissions in biodiesel operated diesel engine with respect to diesel.

4. Summary

From the preceding paragraphs, it may be noted that a lot of experimental and theoretical investigations have been carried out in a diesel engine to study the alternate fuel for diesel. However, the available information for the control of emission and performance improvement of the diesel engine using biodiesel blends with varying operating parameters and catalytic converter are quite limited. Therefore, in the present study an attempt has been made to operating parameters and catalytic converter which are effectively control the NO_x, HC, CO and smoke emissions and also to improve the performance of the diesel engine.

5. Performance improvement and exhaust emissions reductions in biodiesel operated diesel engine through the combination of CR and catalytic converter

Today, viable emission control technologies and improved performance of CI engine can be achieved by means of incorporating design and operating parameters, in-cylinder treatment methods and exhaust gas after treatment methods. Many researchers have reported that combination of the above methods will give better performance and emission reduction.

Hence, in this present review a detailed study has been carried out with combination of increasing CR and catalytic converter (best combination) in biodiesel operated diesel engine.to reduce the emission considerably and improve the performance.

The graphs are plotted for the variation of brake thermal efficiency (BTE), exhaust gas temperature (EGT), specific fuel consumption (SFC), hydro carbon emission (HC), carbon monoxide (CO), oxides of nitrogen (NO_x) and smoke with the brake power.

5.1. Specific fuel consumption (SFC)

The variation of SFC with BP of the engine for the best combination and conventional engine is shown in Fig. 1. It is observed from the graph that the SFC decreases with increasing BP at all loads. It is found from the graph that there is appreciable decrease of SFC for the best combination compared to that of conventional engine. The SFC for best combination is almost closer to diesel fuel at maximum load. This is because of biodiesel and the higher CR leads to effective combustion, which in turn decreases the fuel consumption and provides complete combustion. Further, it is also found that the SFC of the best combination never increases and this may be due to higher viscosity and lower heating value of the biodiesel.

5.2. Brake thermal efficiency (BTE)

Fig. 2 shows the variation of BTE with BP of the engine for the best combination with conventional diesel engine. It is seen from the graph the BTE increases with increasing BP at all loads. It is seen that the BTE for the best combination is lower at all loads when compared to that of conventional diesel engine.

It is seen from the graph that the BTE for best combination is

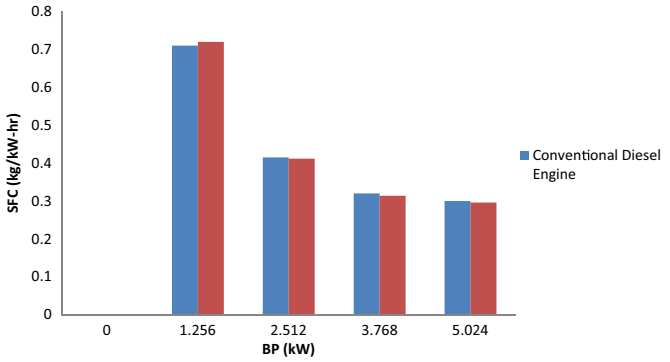

Fig. 1. Variation of SFC with BP for conventional diesel engine and best combination.

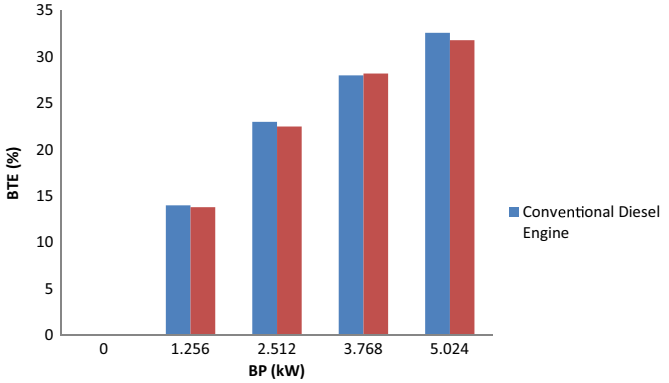

Fig. 2. Variation of BTE with BP for conventional diesel engine and best combination.

almost equal to the diesel at higher load and this is due to the combined effect of biodiesel and higher CR. Further, lowering of BTE is mainly due to lower heating value and higher density of biodiesel when compared to that of conventional fuel.

5.3. Exhaust gas temperature (EGT)

Fig. 3 shows the variation of EGT with BP of the engine for the best combination and conventional diesel engine. It is seen from the graph the EGT increases with increasing BP at all loads. It is seen from the graph that the EGT is lower for best combination at all loads. Further at maximum load the EGT of the best combination is lower than that of conventional diesel engine. The considerable amount of reduction in EGT is due to the lower heating value, higher density and higher viscosity which leads to poor atomization which in turn results in reduction of EGT. Further, all the heat generated will be effectively converted into power output at higher CR.

5.4. Carbon monoxide emission (CO)

The variation of CO with BP of the engine for the best combination and conventional engine is shown in Fig. 4. It is observed from the graph the CO decreases with increasing BP at all loads. It is seen from the graph that the CO emission has been considerably reduced for the best combination at all loads. Further at maximum load, the CO for best combination is lower than that of conventional diesel engine. The combination of biodiesel and CR induces complete combustion due to the presence of excess of oxygen in biodiesel and higher temperature at CR. Further the catalytic converter oxidizes CO into CO_2 in the converter, which in turn gives maximum reduction of CO. The presence of excess oxygen, high cylinder temperature and more catalytic activity in the converter gives maximum reduction of CO emission for the best combination.

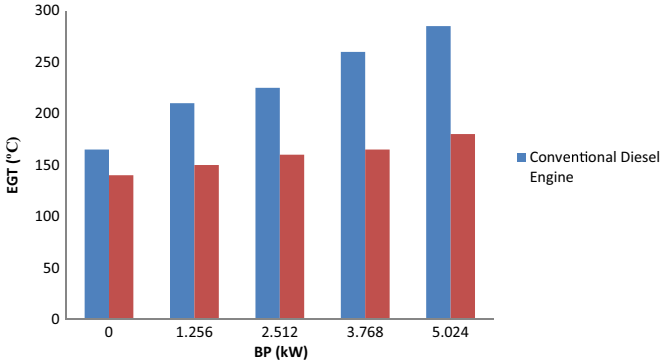

Fig. 3. Variation of EGT with BP for conventional diesel engine and best combination.

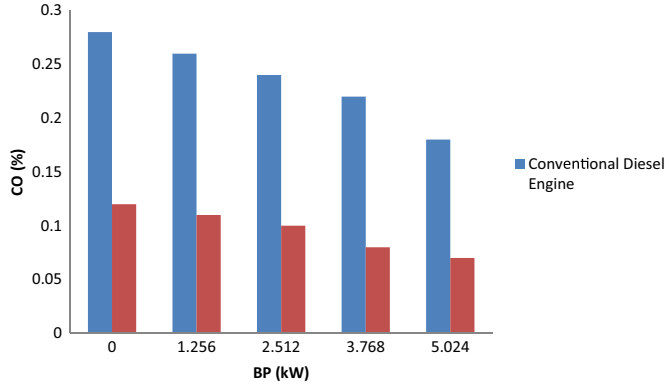

Fig. 4. Variation of CO with BP for conventional diesel engine and best combination.

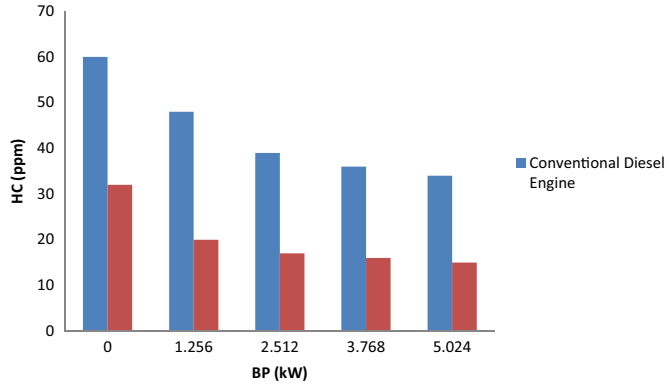

Fig. 5. Variation of HC with BP for conventional diesel engine and best combination.

5.5. Hydrocarbon emission (HC)

The variation of HC with BP of the engine for the best combination and conventional diesel engine is shown in Fig. 5. It is seen from the graph the HC decreases with increasing BP at all loads. Further at maximum load, the HC for best combination is lower than that of conventional diesel engine. It is found that the HC emission is drastically reduced for the best combination at all loads. This is due to the combination of effective oxidization in the converter, presence of excess oxygen in the biodiesel and higher combustion chamber temperature at higher CR.

5.6. Oxides of nitrogen emission (NO_x)

The variation of NOx with BP of the engine for the best combination and conventional diesel engine is shown in Fig. 6. It is found from the graph the NOx increases with increasing BP at all loads. It is seen that the NOx emission for best combination is drastically reduced for the

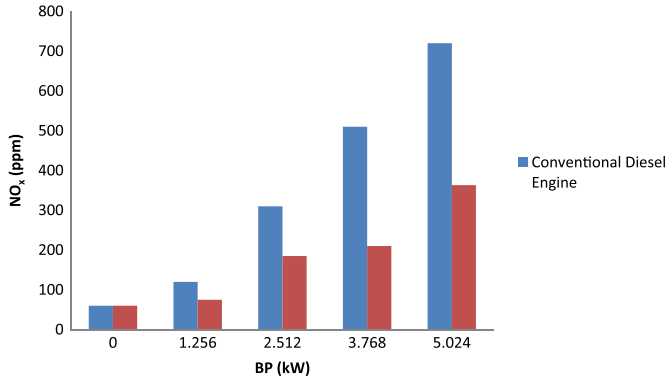

Fig. 6. Variation of NO_x with BP for conventional diesel engine and best combination.

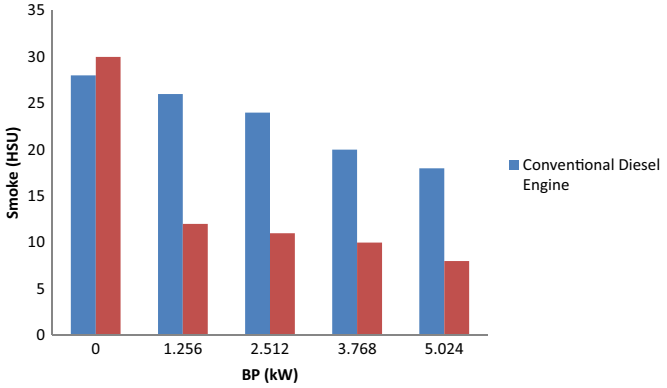

Fig. 7. Variation of smoke with BP for conventional diesel engine and best combination.

best combination at all loads. Further at maximum load, the NOx for best combination is higher than that of conventional diesel engine. This is due to NO present in the exhaust which effectively converted into nitrogen by catalyst in the converter. It proves that drastic reduction of NO_x emission at all loads is due to high catalytic activity of converter.

5.7. Smoke

The variation of smoke with BP of the engine for the best combination and conventional diesel engine is shown in Fig. 7. It is observed from the graph the NOx increases with increasing BP at all loads. It is seen from the graph that the reduction of smoke is achieved for the best combination when compared to conventional diesel engine. This may be due to the higher catalytic activity in the converter. It is found that combination of biodiesel, CR and catalyst coated converter showed the maximum reduction because of high temperature, presence of oxygen and better oxidization and higher catalytic activity in the converter.

6. Conclusion and future researches

The objective of this study was to improve the performance and reduction in exhaust emissions from biodiesel operated diesel engine through CR and catalytic converter. According to the results;

1) The use of biodiesel will lead to loss in BTE due to the reduction in heating value of biodiesel compared to diesel, but there exists power recovery of biodiesel operated diesel engine as the result of an increase in biodiesel fuel consumption.
2) The majority of studies have shown that HC, CO and Smoke emissions were significantly reduced, compared with diesel. The higher oxygen content of biodiesel and lower aromatic compounds has been regarded as the main reasons. The vast majority of literatures agree that NOx emission will increase when using biodiesel. This increase is mainly due to higher oxygen content, cetane number and different injection characteristics.
3) It can be concluded that the blends of biodiesel with small content (B20) by volume could replace diesel in order to help in controlling the emissions except NOx drop in performance. In order to improve the performance of the engine, the operating parameters were changed.
4) Most of researches showed that increase in BTE was observed at higher CR. Further, the HC, CO and Smoke emissions were reduced but increase of NOx emission was observed with increase of CR.
5) It can be concluded that increase of CR with B20 improved the performance and reduction in exhaust emissions except NOx emission. In order to reduce the NOx emission, the catalytic converter was used.
6) It is predominant viewpoint that use of catalytic converter with B20 effectively controlling the NOx emission, HC, CO and Smoke emissions compared to that diesel. Further, there is no variation in performance parameters.
7) The best combination (B20, increase of operating parameters and catalytic converter) along with B20 showed improved in performance and drastic reduction of all emissions than that of conventional diesel engine.

Overall, biodiesel, especially for the blends with a small portion of biodiesel (B20) with increase of CR along with catalytic converter is technically feasible as an alternative fuel in diesel engines with minor modifications to the engine. However, more researches and development in biodiesel resources and engine design are needed.

a) The further studies on biodiesel endurance tests should be executed to make clear the reason and mechanism of wears
b) The further studies on the low temperature performance of biodiesel engine should be fulfilled because biodiesel presents higher viscosity than diesel, which could affect the emissions.
c) The further studies on non-regulated emissions of biodiesel should be carried out to obtain conclusive trend, especially for the carbonyl compounds emissions.
d) The methodology used for measurements need be improved to fulfill the expected requirements.

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